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Structural performance of circular columns confined by recycled GFRP stirrups and exposed to severe conditions

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Abstract Since 1980, Egyptian government investment has been directed to the infrastructure projects. Water supply and water drainage networks are among those projects which are very costly; therefore they are designed with a life span of about one hundred years. There is a new trend toward the use of durable and maintenance free systems. The "GFRP" pipes are one of the economic solutions if the project life span is taken into consideration. A number of investors currently produce the "GFRP" pipes in the Egyptian market and although they follow the latest technologies in their production lines, they still suffer 2–5% deficiency of their produced pipes which consequently regarded as rejected pipes. This percentage has a negative impact on the environmental and economical issues. This research is a trial to investigate the behavior of circular columns confined by GFRP stirrups and exposed to severe conditions. A number of waste pipes were randomly selected and sliced to be used as circular column transverse reinforcement. An experimental program consisting of ten short circular columns was designed to study the effect of corrosion, high degrees of temperature, and sulfate attack on the structural behavior of the axially loaded short circular columns. The experimental results showed that columns laterally reinforced by GFRP slices have a comparable behavior to conventionally reinforced concrete columns especially for those columns exposed to corrosion and sulfate attack.

Introduction

GFRP pipes are one of the most durable solutions for infra structure applications. The use of GFRP pipes has been spread in the Egyptian market in the execution of raw and sewage water pipe lines. Due to the expensive cost of the system, their use still suffers a competition with the conventional systems. One of the reasons, which increase the cost of "GFRP" pipes is the factory rejected pipes at the quality control stage. Most of the Egyptian producers suffer a 2–5% of their product as waste pipes. This percentage represents 900–2250 m length of waste pipes per month if the factory produces 1.5 km of pipes per day. At the moment, all producers throw the rejected pipes in the garbage areas which have a real environmental impact in addition to the loss of their potential value (as the constituent materials of the pipes are imported).

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The problem of understanding the actual effect of confinement on the behavior of axially loaded columns has been widely studied through the last century. Sheikh et al. [1], Martinez et al. [2], and Mander et al. [3], Mossallam [4] have studied most of the governing variables including stirrups spacing, type of steel, and its configuration.

Sheikh and Toklucu [5], Ulaga et al. [6], Abu-Khashaba [7], and Grace et al. [8], studied the durability of the reinforced concrete elements externally strengthened with FRP plates and fabrics under adverse environmental conditions such as humidity, saltwater alkali solution, freeze–thaw, high degrees of temperatures, and sulfate attack. Up to the author's knowledge, no researches are available about the effect of severe conditions on the structural behavior of reinforced concrete columns reinforced laterally by GFRP bars.

In 2005 Sayed [9] has studied the feasibility of recycling the factory rejected GFRP pipes as a lateral reinforcement of reinforced concrete short columns. An experimental program has been designed to study the effect of GFRP tie spacing, slice width, and its own nominal internal pressure on the structural behavior of axially loaded short circular columns. The results showed that the GFRP pipe slices are structurally active in maintaining the structural performance of the columns in comparison with conventionally laterally reinforced concrete columns.

This research is a trial to investigate the durability of the reinforced concrete columns laterally reinforced by recycled GFRP stirrups when exposed to severe conditions. Random waste pipes were sliced to be used as circular column transverse reinforcement ties. An experimental program was designed to study the effect of corrosion, high degrees of temperatures, and sulfate attack on the structural behavior of the axially loaded short circular columns.

Fabrication of "GFRP" pipes

The filament winding process is adopted by most of "GFRP" producers as a production method to fabricate their pipes. As seen in Fig. 1 a mandrel of intended diameter is rotated on its axis, and wound with a continuous filament of reinforcement. The fibers are passed through a resin bath immediately before contact with the laminate. According to the manufacturer's information and fabrication process, the inner and outer surfaces of the pipes are lined and treated against the chemical attack of the adherent severe environment. A strict quality control system is applied on each pipe just before its delivery to the site. Each pipe is pressured by water in 1.5 times its designed pressure then the pipe is inspected for any leakage. The factory repairs the leakage area and retests the pipe and in case the leakages continue, the pipe is identified as rejected and the leakage area is highlighted by red color then the pipes are thrown away in the rejected yard of the factory. From these facts, the term "rejected pipe" describes a pipe that contains a point of water leakage and in all cases the point length does not exceed 20 from 3000 mm which is the full length of the pipe. The rejected pipes not only have a negative environmental impact but also have an economical bad effect.

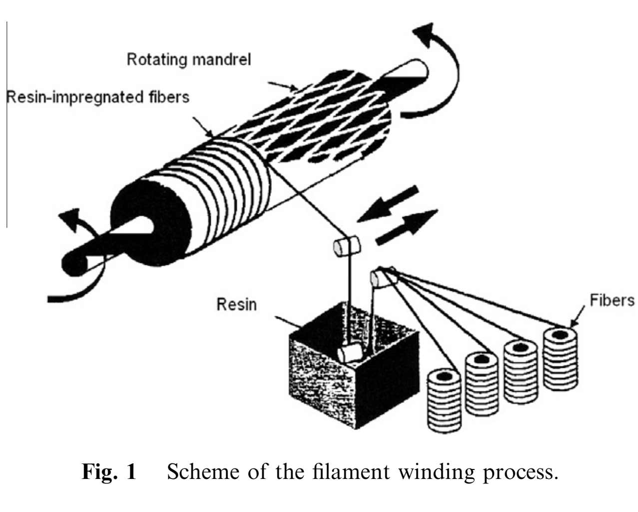

Fig. 1 Scheme of the filament winding process.

Research program

The experimental program consisting of ten short circular columns was designed to study the effect of corrosion, high degrees of temperatures, and sulfate attack on the structural behavior of the axially loaded short circular column. Fig. 2 shows the configuration of columns laterally reinforced by GFRP slices. Table 1 shows the specimens configuration. Columns C1 and C2 were tested as control specimens and were reinforced laterally by 8 mm diameter steel rebar and GFRP slices, respectively. The distance between the circular steel and GRRP stirrups was kept constant for all the tested columns at 160 mm. Columns C3 and C4 were reinforced with steel and GFRP lateral reinforcement respectively, and they were exposed to high degrees of temperatures. Columns C5 and C6 were reinforced laterally by steel rebar and GFRP slices, respectively, and were exposed to corrosion for about one year. Columns C10 and C9 were typical to columns C5 and C6 and were exposed to the corrosion for two years. Columns C7 and C8 were reinforced laterally by GFRP slices and steel rebar, respectively and were exposed to 5% magnesium sulfate to study the effect of sulfate on the steel and GFRP columns.

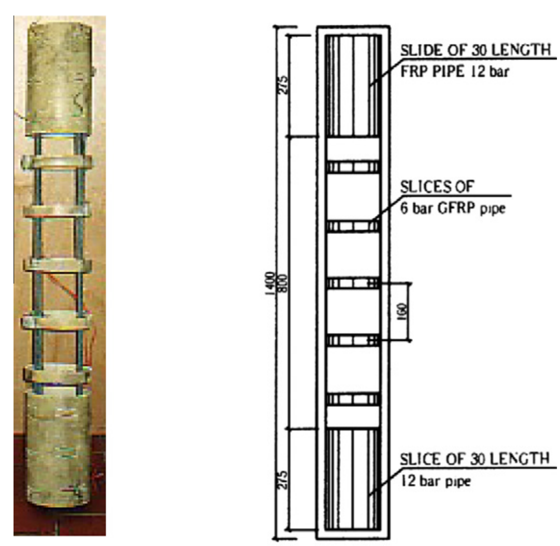

Fig. 2 Configuration of columns laterally reinforced by GFRP slices.

Table 1 Specimens' configuration.

Column Id	Type of lateral reinforcement	Notes
C1	Steel – 8 mm	Control
C2	GFRP – 6 bar	
C3	Steel – 8 mm	Subjected to high degrees of
C4	GFRP – 6 bar	temperatures (2 h)
C5	GFRP – 6 bar	Corrosion about one year
C6	Steel – 8 mm	
C7	GFRP – 6 bar	Submerged in sulfate for one
C8	Steel – 8 mm	year (5%)
C9	Steel – 8 mm	Corrosion about two years
C10	GFRP – 6 bar	

Fig. 3 Ring tensile test of the recycled GFRP pipes.

Preparation of concrete mixture

A concrete mix was designed to cast the tested columns. The target concrete strength fcu is (27.50 N/mm^2). Portland cement according to Egyptian Standard Specification 4756/2007, crushed limestone coarse aggregate according to Egyptian Standard Specification 1109/2001 with maximum nominal size of 12 mm, and natural fine aggregate (Sand) according to Egyptian Standard Specification 1109/2001 with maximum nominal size of 4.75 mm were used for casting all columns. Superplasticizer admixture complying with ASTM C494 Type F was used to achieve good workability. Table 2 shows the mix proportions of the concrete mix. Six standard cubes ($15 \times 15 \times 15$ cm) were tested at the ages of 7 and 28 days in addition to three standard cylinders (150×300 mm) which were tested at the age of 28 days to verify the obtained target strength.

The GFRP recycled pipes

Three GFRP pipes of 6 m length were randomly selected from the factory waste area to be used, after slicing, as transverse reinforcement. All the rejected pipes were received in 300 cm length accompanied with full description and highlighting of the leakage points on the pipes. During the sawing of the pipes into slices the defected slices were thrown away. The GFRP pipes were sliced into slices of 30 mm height as shown in Fig. 3 then a direct tensile test was applied according to ASTM D 2290-92 [10] to get the tensile strength of the used pipes. Table 3 shows the test results of the used pipes. Also, Fig. 3 shows a pipe ring during test.

Fabrication of tested columns

Two steel forms were prepared for casting the concrete. Concrete was cast in the Material Laboratory of Housing and Building National Research Center at 25 °C temperature. The sides of the form were removed after 48 h. Curing of specimens with water started immediately after casting and continued for 14 days. Deformed high tensile steel with yield strength of 420 N/mm^2 and ultimate strength of 630 N/mm^2 was used for all columns. Also, mild steel with yield stress of 280 N/mm^2 and ultimate stress of 410 N/mm^2 was used for five columns C1, C3, C6, C8, and C9. To avoid the premature failure, the column heads were reinforced with GFRP slides of 300 mm length and 12 bars pressure grade in the shape of transverse reinforcement of column at its ends in order to give enough confinement to overcome stress concentration at those ends.

Table 3 Results of the direct tensile test of the GFRP pipe rings.

Pressure grade of the used pipe	Ultimate tensile load (KN)	Cross section area (mm^2)	Tensile strength kN/mm^2
6 bar	22.0	140	780
12 bar	47.0	138	170.0

Accelerated corrosion technique

The second adopted severe condition was speeding up the rate of corrosion of the steel reinforcement in order to induce deterioration in the columns. Therefore, four columns were subjected to the electrochemical accelerated corrosion technique namely C5, C6, C9 and C10. The corrosion setup consisted of the test specimen, stainless steel plates (acting as an artificial cathode), a wet medium between the stainless steel plate and the columns, and a D.C. power supply. The wet medium was burlap wetted by 3% NaCl solution. It should be noted that the cathode stainless steel plate was mounted around the column but not extended to the heads in order to avoid premature failure. The value of the applied current intensity was about 10 $\mu A/mm^2$ for all of the corroded specimens. The applied current was maintained constant for all specimens by using a variable resistance and was monitored by means of an ammeter. Fig. 4 shows the electrochemical accelerated corrosion setup. The columns C5 and C6 were exposed to corrosion for one

Table 2 Mix proportions of designed concrete mix.

Cement (kg)	Dolomite crushed stone (kg)	Sand (kg)	Water (liter)	Super-plasticizer type (*F*) (liter)
350	1185	590	200	5.50

year while the columns C9 and C10 were exposed to corrosion for two years. The half-cell test (Cu/CuSo$_4$) was carried out on the corroded columns. The recorded potential readings for these columns were below −350 mv, which infers according to the ASTM standard C 876 a 90% probability of corrosion. After the determined exposure period to the corrosion systems, visual inspection was used in determining the delaminated parts of the concrete cover.

High degrees of temperatures technique

Fig. 5 shows the furnace which was designed to apply the testing load on specimens during the exposure to high degrees of temperatures. The furnace was made of outside steel plate and inside ceramic fiber sheets for isolation and provided with electric Nickel Chrome heaters. The furnace openings were surrounded by glass wool to prevent or reduce the losses of the elevated temperatures. The furnace was provided with a thermostat and control unit for controlling and monitoring of the applied temperature, respectively. The tested column was under the head of the 5000 kN hydraulic loading machine. The tested columns C3 and C4 were heated under the application of a constant vertical load level that equals 50% of the ultimate load determined from testing the control column C1. The furnace was installed under the machine and around the tested column. The furnace was switched on until reaching the target temperature. After exposing the tested column to the target temperature for the planned period, the furnace was switched off and the load was released then the furnace was moved away from the column. The column was left to cool gradually in air for 24 h and then reloaded until failure to record the residual strength.

Sulfate attack

Steel and GFRP columns were immersed in 5% of magnesium sulfate ($MgSO_4$) solution for one year. The test was carried out to examine the sulfate resistance of column laterally reinforced by GFRP slices and compared it with that of conventionally reinforced concrete columns. The specimen capacity losses due to sulfate attack were determined.

Test setup and instrumentation

The specimens were tested up to failure using AMSLER compression testing machine of 5000 kN capacity. The testing machine consists of a lower moving piston which moves on a spherical head covered by a plate so that the applied load is always passing through the center of the sphere, and perpendicular to the column's cross section. On the other hand, the

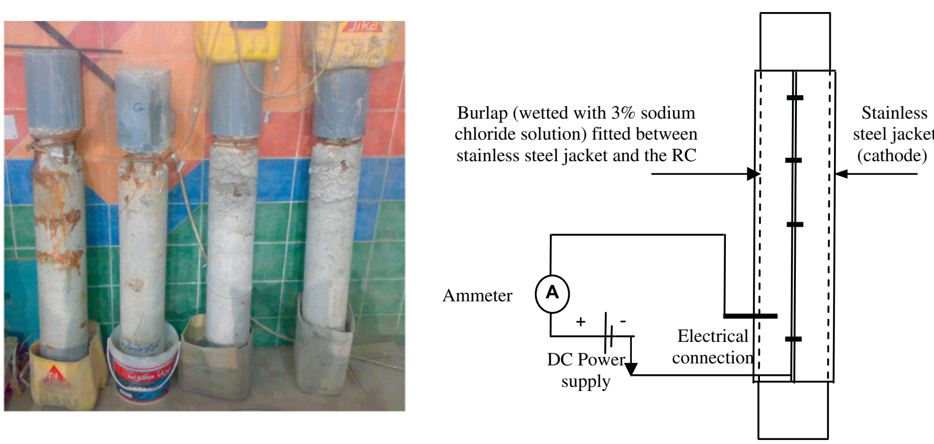

Fig. 4 Electrochemical accelerated corrosion setup.

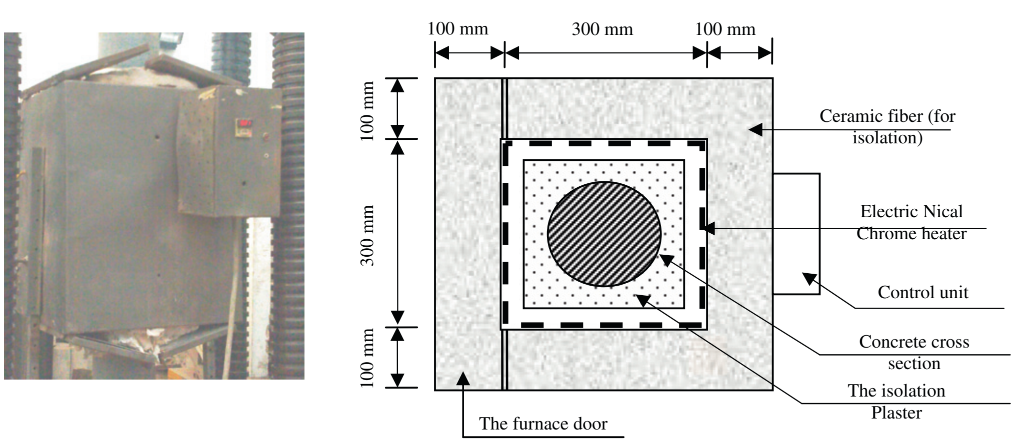

Fig. 5 Furnace used for applying high degrees of temperatures.

upper plate is moving around a fixed sphere. A 5000 kN load cell was used to record the compressive load. The specimen was placed on a lower bearing plate and the load was applied through an upper one. The axial displacement of the column was measured using linear variable distance transducers, (LVDT's) with a length of 600 mm. The LVDT's were attached to the side of RC column using 3 mm fisher bolts.

Discussion of test results

All test results are summarized in Table 4; the table contains the ultimate load of each column, the initial stiffness, and the toughness. The experimental results show the relation between axial strain and the ultimate load of each column. Toughness of columns is defined as the area under the load–vertical strain curve, which represents the energy absorption capacity of the column. Toughness values of the different columns were calculated numerically based on the recorded load–vertical strain relationships. The initial stiffness is defined as the initial slope of the linear zone of the load strain curve. The maximum load carrying capacity was recorded for the control column C1 with steel stirrups which was failed at 1332 kN followed by the control column C2 with GFRP stirrups where the ultimate load reached 1266 kN. The minimum load carrying capacity of 575 kN was recorded for column C4 with GFRP stirrups and exposed to high temperature. The maximum toughness of 2.31 kN mm/mm was recorded for column C2 with GFRP stirrups which could be attributed to the increased volume of concrete confined by the GFRP slices in comparison with the concrete confined by the 8 mm steel stirrups. The subsequent section will discuss the performance of the tested column after exposure to the severe conditions of high temperature, corrosion, and sulfate attack.

Table 4 Test results of the tested columns.

Specimen	Ultimate load (kN)	Toughness (kN mm/mm)	Initial stiffness (kN mm/mm)
C1	1332	2.18	992765
C2	1266	2.31	781196
C3	720	0.77	632088
C4	577	0.57	536670
C5	922	2.17	770370
C6	863	1.97	546735
C7	1062	1.82	707083
C8	937	1.10	801870
C9	772	1.36	421288
C10	825	1.98	534972

Failure mode of columns

Fig. 6 shows the failure modes of all columns. The failure mode of column C1 was brittle failure and the concrete crushed suddenly when the axial ultimate load was reached and finally the load dropped to relatively low value when the column failed. Prior to the column failure, the longitudinal reinforcing bars buckled between transverse hoops. The failure

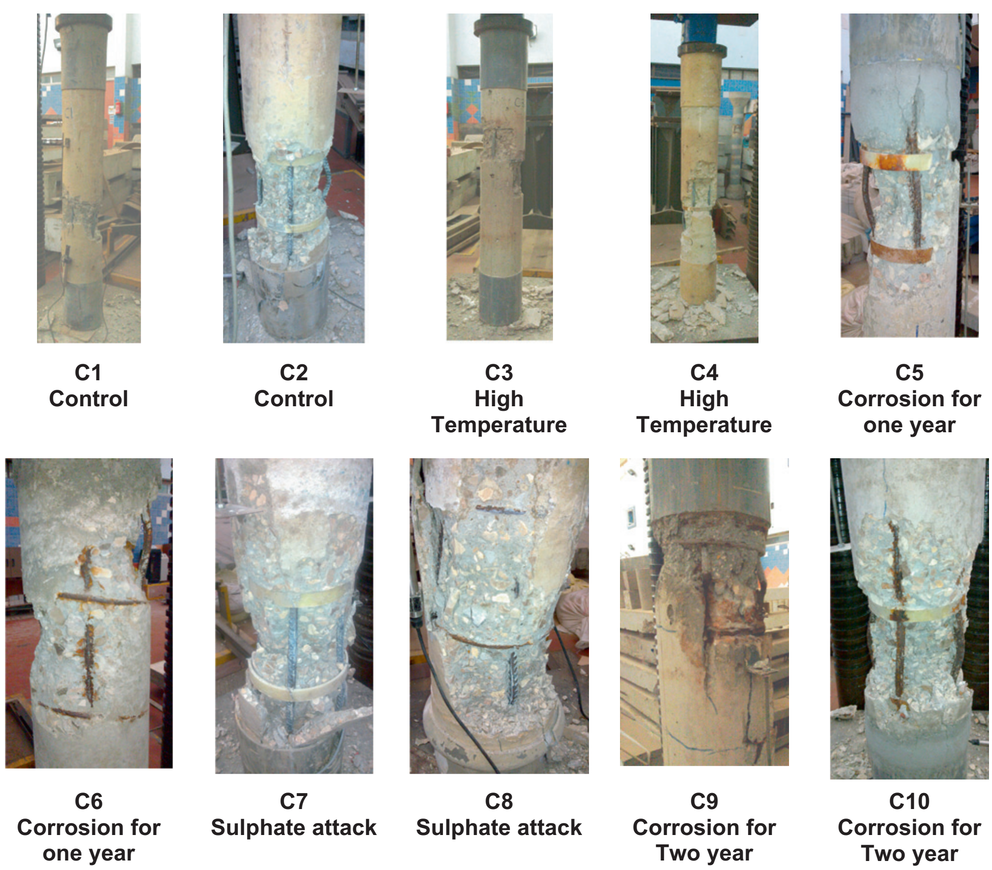

Fig. 6 Failure modes of all tested columns.

mode of column C2 was due to separation of concrete cover followed by sudden rupture of GFRP stirrups when the axial ultimate load was reached. The load dropped to relatively low value when the column failed.

For columns exposed to high temperature, there was no obvious difference in the failure mode between unheated columns C1 and C2 and heated columns C3 and C4. For columns exposed to the corrosion condition, the failure mode of columns C6 and C9 was due to cutting of corroded steel stirrups followed by crushing of concrete as shown in Fig. 6. This failure mode was brittle compression failure. In general, failure is less brittle than the failure of column C1. The failure mode of columns C5 and C10 was similar to that of column C2. Regarding columns exposed to sulfate attack, the failure modes of columns C7 and C8 were similar to those of columns C2 and C1, respectively.

Effect of severe conditions

The effect of the severe conditions on the structural behavior of the tested columns will be presented and discussed in the subsequent sections. The severe conditions studied in this research program were high degrees of temperatures, corrosion, and sulfate attack.

Effect of high degrees of temperatures

The effect of high degrees of temperatures can be presented by comparing the behavior of columns C1, C2, C3 and C4. Columns C1 and C3 were reinforced laterally by steel stirrups where columns C2 and C4 had GFRP stirrups. Fig. 7 shows the load–strain relationships of columns C1, C2, C3 and C4. From the results shown in Table 4 and the load–strain behavior shown in Fig. 7, the following points could be noticed:

(1) The toughness reduced from 2.18 to 0.77 for C1 and C3 where it reduced from 2.31 to 0.57 for C2 and C4. It is worth to note that, the toughness of column C2 with GFRP stirrups was slightly higher than that of column C1 with steel stirrups by 6%; and this increase could be attributed mainly to the ductile behavior of GFRP stirrups. After exposure to high temperature, the toughness of column C3 with steel stirrups was higher than that of column C4 with GFRP stirrups by 35%.

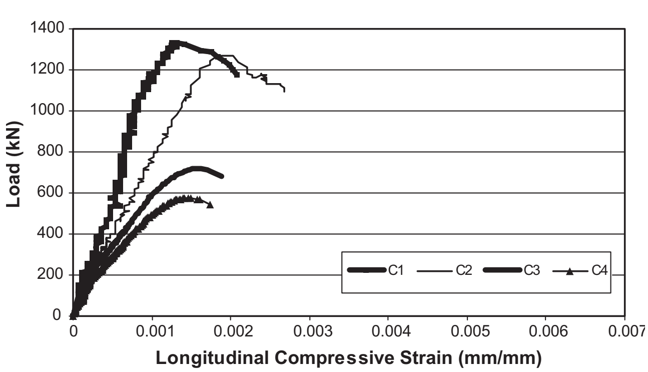

Fig. 7 Load–longitudinal compressive strain relationship for columns C1, C2, C3, and C4.

(2) The reduction value of toughness for column with steel stirrups after exposure to high degrees of temperature was smaller than that of column with GFRP stirrups by 10%. This behavior was due to the decrease in the shearing strength of structural epoxy of GFRP fabrics due to continuous exposure to the high temperature conditions which led to significant reduction in load-carrying capacity and toughness caused due to onset of delamination.

(3) The ultimate loads of columns C3 and C4 were 54% and 46% of those of columns C1 and C2, respectively and the reduction of load-carrying capacity for columns with steel stirrups (C1 and C3) after exposure to high degrees of temperature was smaller than that of columns with GFRP stirrups (C2 and C4) by 8%.

(4) The initial stiffness of columns reinforced laterally by steel reinforcement was higher than that value recorded for column reinforced laterally by GFRP slices either before or after exposure to high degrees of temperatures. For the control columns C1 and C2, the initial stiffness of column C1 was higher than that of column C2 by 27% additionally; the stiffness of column C3 with steel stirrups was higher than that of C4 with GFRP slices by 17.70%. On the other hand, when the control columns C1 and C2 were exposed to the elevated temperature, the initial stiffness of columns C3 and C4 were 64% and 68% of those of columns C1 and C2, respectively.

(5) Although the overall structural performance of column C2 with GFRP slices was close to that of column C1 with steel stirrups, both heated columns C3 and C4 were negatively affected in all aspects of the structural behavior with a great reduction of ultimate load, toughness, and initial stiffness for column C4 with GFRP slices.

Effect of corrosion

The effect of corrosion can be presented by comparing the behavior of columns C1, C2, C5, C6, C9 and C10. Columns C1, C6 and C9 had steel stirrups while columns C2, C5 and C10 had GFRP stirrups. Columns C5 and C6 were exposed to corrosion for one year where columns C9 and C10 were exposed to corrosion for about two years. Fig. 8 shows the load–vertical strain relationships of columns C1, C2, C5 and C6 additionally, Fig. 9 shows the load–strain relationships of columns C1, C2, C9 and C10. From both figures and the test results shown in Table 4, the following findings could be deduced:

(1) For columns with steel stirrups, corrosion for one and two years decreased the column capacities by 35% and 42%, respectively, while for columns with GFRP stirrups, corrosion for one and two years decreased the column capacities by 27% and 34%, respectively.

(2) For the columns with steel stirrups C6 and C9, the corrosion for one and two years decreased the toughness by 10% and 37% compared with control column C1, respectively. For two years corroded column with steel stirrups C9, high reduction in the area of corroded lateral steel reinforcement was observed. This decreased the toughness by 30% compared with that of one year corroded column.

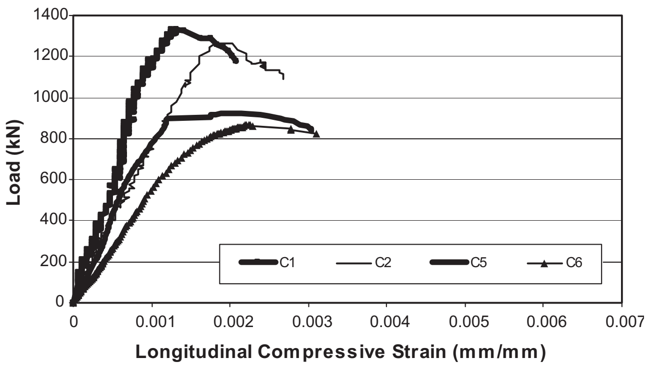

Fig. 8 Load–longitudinal compressive strain relationship for columns C1, C2, C5, and C6.

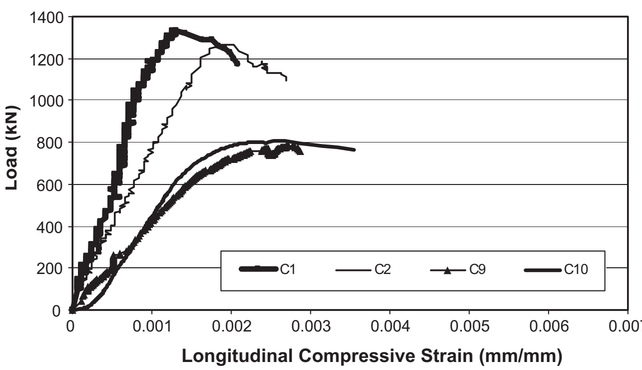

Fig. 9 Load–longitudinal compressive strain relationship for columns C1, C2, C9, and C10.

(3) For columns with GFRP stirrups, the corrosion for one and two years slightly decreased the toughness by 6% and 14%, respectively. The advantage of GFRP slices over steel stirrups in terms of toughness came from their height. The GFRP height is 30 mm in comparison with 8 mm for steel stirrup which has the ability to confine more of the concrete volume as shown in Fig. 10.
(4) For columns with steel stirrups, corrosion for one and two years decreased the initial stiffness by 45% and 58%, respectively while for columns with GFRP stirrups, corrosion for one and two years decreased the initial stiffness by 2% and 32%, respectively.

From these results, it could be noticed that columns with GFRP stirrups are less susceptible to corrosion conditions than the columns with steel stirrups. This could be attributed mainly to the fact that, GFRP slices has strong resistance to the severe corrosion conditions. This result encourages the use of this system in marine environment.

Effect of sulfate attack

The effect of sulfate attack can be presented by comparing the behavior of columns C1, C2, C7, and C8. Columns C1 and C8 had steel stirrups while columns C2 and C7 had GFRP stirrups. Fig. 11 shows the load–strain relationships of columns C1, C2, C7 and C8. The following notes could be included from Fig. 11 and Table 4:

(1) The ultimate loads of columns C8 and C7 were 70% and 84% of those of columns C1 and C2, respectively. This finding indicates that column C8 which was reinforced by steel stirrups was affected by the sulfate attack more than column C7 which was reinforced by GFRP slices. This result could be explained by the role of sulfate in attacking concrete. The chemical compound that results from sulfate attack has an expansion tendency which induces internal cracks on the surface and outer shell of the column core. The GFRP slices by its 30 mm height have prevented the internal micro-cracks more than the role of the steel stirrups.

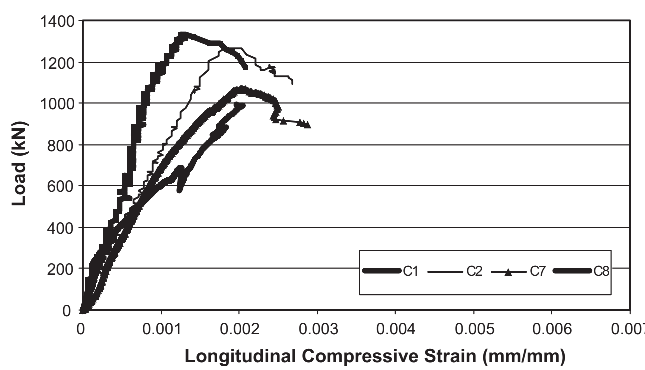

Fig. 11 Load–longitudinal compressive strain relationship for columns C1, C2, C7 and C8.

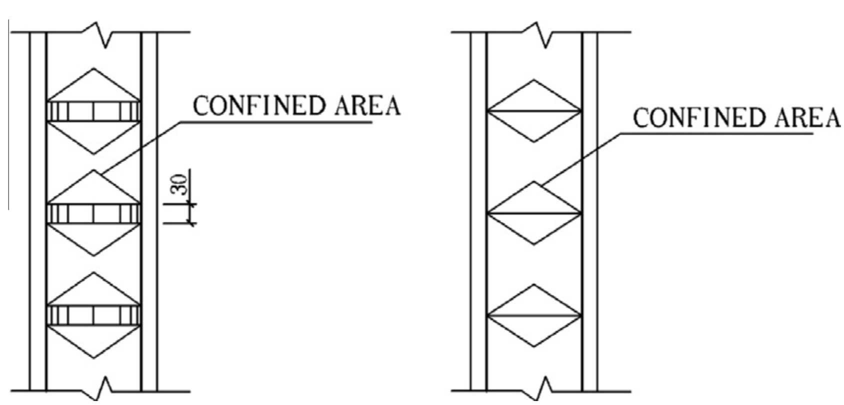

Fig. 10 Confined area by GFRP and steel stirrups.

(2) The initial stiffness of columns C8 and C7 were 81% and 90% of those of columns C1 and C2, respectively. In terms of toughness, the toughness of columns C8 and C7 were 51% and 79% of those of columns C1 and C2, respectively.

It could be included that a long-term exposure to sulfate attack up to an age of one year had less negative effect on both of the load carrying capacity and the toughness of column with GFRP stirrups compared with those of column with steel stirrups.

Conclusions

The following conclusions can be drawn from the results of the research carried out to study the structural performance of circular columns confined by GFRP stirrups and exposed to severe conditions namely high degrees of temperatures, corrosion attack, and sulfate attack.

1. Columns reinforced laterally by recycled GFRP stirrups are less susceptible to both of corrosion and sulfate attack in comparison with columns laterally reinforced by steel stirrups. The load carrying capacity of columns laterally reinforced by recycled GFRP stirrups and exposed to corrosion or sulfate attack was slightly higher than those of columns laterally reinforced by steel stirrups.
2. Application of GFRP stirrups as lateral reinforcement should be avoided on the building exposed to high degree of temperatures and it is recommended to increase the column's external-cover beyond those values recommended by the Egyptian Code for steel laterally reinforced columns.
3. Confining with GFRP stirrups increased the structural ductility of the columns significantly in comparison with those of columns reinforced laterally with traditional steel reinforcement.
4. Failure mode of columns with GFRP stirrups is less brittle than that of columns with steel stirrups.
5. Although the research findings have shown pronounced promising structural performance for GFRP laterally reinforced columns, additional research effort is still needed to cover other parameters which could affect the resistance of the concrete column laterally reinforced by the GFRP stirrups in severe conditions. The size effect of the column cross section, the grade of the GFRP pipes, and the exposure to chemical solution are among those variables recommended to be studied.
6. It is mandatory to apply a strict quality control system during the use of the rejected GFRP pipes as lateral reinforcement of reinforced concrete columns in order to extract the leakage part of the pipe and only use the sound ones.
7. Prior to the introduction to the construction industry, it is recommended to construct a prototype of one story building and inspect the loaded columns laterally reinforced by the GFRP pipes until a full confidence of their behavior is fulfilled.

References

[1] S. Sheikh, S.M. Uzumeri, Strength and ductility of tied concrete column, J. Struct. Eng. 106 (No. ST5) (1980) 1079–1102. ASCE.
[2] S. Martinez, A.H. Nilson, F.O. Slate, Spirally reinforced high-strength concrete columns, ACI J., Proc. 81 (9) (1984) 431–442.
[3] J.B. Mander, M.J.N. Priestley, R. Park, Observed stress–strain behavior of confined concrete, ASCE Struct. J. 114 (8) (1988) 1827–1849.
[4] A.I. Mossallam, Confinement Effectiveness of Axially Loaded Concrete Members Confined by Lateral Reinforcement, M.Sc. Thesis, Faculty of Engineering, Cairo University, Egypt, 1999.
[5] S. Sheikh, Toklucu, Reinforced concrete columns confined by circular spirals and hoops, ACI Struct. J. 90 (5) (1993) 542–553.
[6] T. Ulaga, U. Meier, Long-term behavior of CFRP-laminate-strengthened concrete beams at elevated temperatures, International Conference FRPRCS-5: Externally Bonded Reinforcement for Flexure, London, 2001, 147-155.
[7] Mohamed I. Abu-Khashaba, Bond of concrete-CFS after exposing to high percentage of humidity, International Conference Structural Composites for Infrastructure Applications, Aswan, Egypt, 2002.
[8] Nabil F. Grace, S.B. Singh, Durability Evaluation of carbon fiber-reinforced polymer strengthened concrete beams: experimental study and design, ACI Struct. J. 102 (1) (2005) 40–53.
[9] M.S. Sayed, Recycling of factory rejected GFRP pipes as transverse reinforcement for reinforced concrete short circular columns, Proceeding of The Forth Middle East Symposium For Composite Materials in Infrastructure Applications, Alexandria, Egypt, 2005.
[10] ASTM D 2290-08: Standard test method for apparent hoop tensile strength of plastic or reinforced plastic pipe by split disk method.